by Ferrel, namely, the heat evolved by the condensation of vapor into cloud and rain.

Second. The surplus energy derived from the underflow of the cold air from polar regions toward the equator, and the return of the equatorial air toward the pole, the importance of which has been especially insisted upon by Professor Bigelow.

These polar and equatorial currents may be superposed vertically or may flow on side by side laterally. In the former case they roll over and over each other where they meet, and form roll clouds, roll cumuli, roll cirrus, and bring sudden changes from warm to cold and from cold to warm, with a preliminary slight dash of rain. In the latter case they whirl around a central region with a grand sweep, with southerly winds on the east and northerly winds on the west side, in the Northern Hemisphere, and the whole system moves along over the surface of the globe day after day; there is usually heavy rain on the east side, and according to Ferrel this must contribute to the maintenance of the whirl.

These great whirls with low pressure at the center lie between much larger areas of high pressure, and are sometimes said to be fed by them. After they have moved northward beyond the influence of the high pressure of the North Temperate Zone and approach the Arctic Zone, they seem to die away, and we do not yet know enough about the storms north of 65° north latitude to say with certainty whether they are straight-line gales or hurricanes.

We have used the words "whirlwind," "hurricane," and "tornado" because there can be no doubt what is meant by these terms. The technical meteorologists would use the single word "cyclone," or "area of low barometer," or simply "low;" but we have avoided the use of the word "cyclone" because our correspondent, like many other writers and the whole newspaper fraternity, has applied the word "cyclone" specifically to tornadoes, which we think is very objectionable. Of course we recognize the fact that the English language is in a state of perpetual change and the usage of one century is sure to differ from that of the next, but it is not common in scientific literature to arbitrarily change the meaning of such a specific word as "tornado."

The word "cyclone" was devised as equivalent to a special theory as to how the wind moves in hurricanes on the ocean, and ought never to have been applied to a tornado. That erroneous usage began, so far as we know, with a popular sensational newspaper writer in 1875. Another similar writer endeavored to go him one better by introducing the French word *tourbillion* as being a little more high-sounding than the correct French word *tourbillon*. We could wish that this usage had survived, as it would have saved us the annoyance of the popular confusion of the terms "tornado" and "cyclone."—*C. A.*

A METHOD OF PREDICTING THE MOVEMENT OF TROPICAL CYCLONES.

By Mr. MAXWELL HALL. Dated Montego Bay, Jamaica, W. I., February 19, 1906.

At the given time and place let p be the pressure, i. e., the reading of the barometer in inches and decimals of an inch, corrected for instrumental error, reduced to 32° F., sea level, and standard gravity, and further corrected for diurnal variation; let p_m be the mean value of p for the season; let $\Delta p = p_m - p$, so that Δp is the fall of pressure below the mean; and let r be the distance, in miles, between the observer and the nearest edge of the central calm area of the cyclone.

Let a line be drawn from the center through the place of observation to the outer limit of the cyclone; then along that line, and except when near the central calm, we have the equation—

$$\Delta p = \frac{c}{\sqrt{r - a}} \qquad (1)$$

a and c are constants along the line; and if a curve be drawn showing the relation between Δp and r it will be found that Δp leaves the curve at a certain point near the central calm, and then follows the tangent to the curve at that point until it reaches the calm.

This statement applies only to tropical cyclones; in higher latitudes other forces, such as the effect of the rotation of the earth, render equation (1) quite inapplicable.

Let us take as an example the Jamaica cyclone of August 11, 1903. The center moved in a remarkably straight line from Martinique to Jamaica, and on to the Cayman Islands, at the rate of 20 miles an hour, and as the edge of the central calm reached Montego Bay at 9:15 a. m., there is no difficulty in obtaining the different values of r given in the fifth column in Table 1. The different values of Δp were found by taking p_m to be 29.928.

TABLE 1.—*Montego Bay, August, 1903.*

Day and hour.	p	Δp	Wind.	r	Δp Computed.
	Inches.	*Inches.*	*M. p. h.*	*Miles.*	*Inches.*
10th, 6 p. m.	29.837	0.09	3	305	0.11
11th, 6 a. m.	29.686	.24	10	65	.24
11th, 7 a. m.	29.609	.32	20	45	.29
11th, 8 a. m.	29.520	.41	50	25	.39
11th, 8:15 a. m.	29.478	.45	60	20	.45
11th, 8:30 a. m.	29.427	.50	60 to 80	15	.52
11th, 8:45 a. m.	29.331	.60	60 to 80	10	.67
11th, 9 a. m.	29.16	.77	60 to 80	5	*0.77
11th, 9:15 a. m.	28.93	1.00	0	0	....

*Measured along the tangent to the curve.

In order to plot the curve showing the connection between Δp and r, take a scale of 40 divisions to an inch, let each division represent a mile along the horizontal line, and let each division represent 0.01 inch of Δp down the vertical line.

In fig. 1, Plate I, the dots surrounded by small circles show the observed values of Δp, while the curve is drawn among them with a free hand.

From the smooth curve we have,

r	Δp
80.........	0.22
60.........	0.25
40.........	0.32
20.........	0.45

and then from equation (1) we have, approximately,

$$a = +2$$
$$c = 1.9.$$

To solve the equations by the method of least squares would be a waste of time; the nature of the work permits only approximate values. From these values of a and c, Δp was computed, and the results given in the last column of Table 1.

The close agreement between the observed and computed values of Δp shows that equation (1) suits this particular cyclone.

It will be noticed that Δp leaves the curve when r is about 5, Δp about 0.77, and the wind blowing a hurricane. For values of r less than this, or even less than 10, equation (1) gives values of Δp absurdly large. The tangent is drawn through 1.05, the lowest pressure.

As a second example let us take the Jamaica cyclone of August 20, 1886. It passed centrally over Kingston, along a line joining Kingston and Montego Bay, at the rate of twelve miles an hour; but near Montego Bay it turned northward. (Jamaica Weather Report No. 69). The effects of the small, secondary cyclone near St. Anns Bay were entirely local; it did not perceptibly affect the barometer at either Kingston or Montego Bay. (See Table 2.)

The different values of Δp were found by taking $p_m = 29.914$. The lull at the center lasted for about half an hour, from 3:30

to 4:00 a. m.; but as the center did not pass exactly over the place of observation, we must avoid small values of r.

TABLE 2.—*Kingston, August, 1886.*

Day and hour.	p	Δp	Wind.	r	Δp computed.
	Inches.	*Inches.*	*M. p. h.*	*Miles.*	*Inches.*
19th, 7 a. m.	29.773	0.14	3	246	0.13
19th, 3 p. m.	.745	.17	3	150	0.17
19th, 11 p. m.	.618	.30	6	54	0.31
19th, 12 midnight	.498	.42	12	42	0.37
20th, 1 a. m.	.418	.50	35	30	0.51
20th, 2 a. m.	.257	.66	60	18	*0.65
20th, 3 a. m.	.159	.76	40	...	*0.81
20th, 3:30 a. m.	29.123	0.79	0	...	*0.90

*Measured along the tangent to the curve.

From the smoothed curve (see fig. 2, Plate I) we have

r	Δp
140	0.17
60	0.27
30	0.50

whence $a = +16$, $c = 1.9$ and thence the computed values of Δp in Table 2.

It will be noticed that Δp left the curve when r was about 30, and the wind not more than 35 miles an hour. But Kingston is sheltered from winds from the north, and this wind-velocity may be too small in consequence.

We shall use these values of a and c for the same cyclone, when approaching Montego Bay. (See Table 3.)

TABLE 3.—*Montego Bay, August, 1886.*

Day and hour.	p	Δp	Wind.	r	Δp computed.
	Inches.	*Inches.*	*M. p. h.*	*Miles.*	*Inches.*
19th, 7 a. m.	29.782	0.13	0	329	0.11
19th, 4 p. m.	29.778	.14	0	221	.13
19th, 7 p. m.	29.753	.16	28	185	.15
19th, 11 p. m.	29.716	.20	23	137	.17
20th, 2 a. m.	29.688	.23	34	101	.21
20th, 4 a. m.	29.667	.25	34	77	.24
20th, 7 a. m.	29.622	0.29	23	41	0.38

The distance between Kingston and Montego Bay is 83 miles. After 7 a. m. of the 20th some great change occurred; the cyclone swerved on its course, which was no longer a straight line.

Let us take as a last example the destructive cyclone of October 29, 1867, which passed in a straight line centrally over the harbor of the small island of St. Thomas, in the West Indies. Prof. J. R. Eastman, U. S. N., made a report on this cyclone, and the data for Table 4 are taken from that report, published at Washington, in 1868, in the annual volume of the U. S. Naval Observatory.

TABLE 4.—*St. Thomas, October, 1867.*

Day and hour.	Barometer.	Δp	Wind.	r	Δp computed.
	Inches.	*Inches.*		*Miles.*	*Inches*
29th, 7 a. m.	29.76	0.20	....	98	0.20
29th, 8 a. m.	29.75	.22	....	82	.22
29th, 9 a. m.	29.73	.26	....	68	.24
29th, 10 a. m.	29.72	.27	....	52	.28
29th, 11 a. m.	29.69	.28	....	38	.33
29th, noon	29.64	.31	Hurricane.	22	.48
29th, 1 p. m.	28.86	1.06	....do	8	*1.02
29th, 1:30 p. m.	28.50	1.42	Calm	0	*1.47

*Measured along the tangent to the curve.

The above barometric readings were further corrected for diurnal variation and standard gravity, whence p and then Δp were found by taking $p_m = 29.88$.

The velocity of the center along its westerly course was 15 miles an hour; the calm at the center lasted half an hour, and the wind blew with hurricane force for an hour and a half before the passage of the central calm, and for an hour after.

It is more difficult to deduce a and c for this storm than for the two preceding ones; however, adopting

$$a = +6$$
$$c = 1.9$$

we have Δp in the last column of Table 4.

Table 4 and its corresponding figure (fig. 3, Plate I) are very remarkable; the fall before noon was very small, and the fall during the following hour and a half very large. It will be noticed that the gradient here is no greater than in the first figure, and probably the wind was no stronger, 60 to 80 miles an hour, in gusts; and when Mr. T. H. Jahnecke stated that the wind rose to 74 miles an hour his estimate was probably correct as an average.[1]

We shall measure gradients by the fall of pressure in inches of mercury per mile toward the center. But in the above figures the vertical scale was taken to be a hundred times the horizontal scale according to the adopted units, an inch and a mile. So that if φ be the angle the tangent at any point of the curve makes with a horizontal line through the point, the

$$\text{gradient} = \frac{\tan \varphi}{100}.$$

Thus in fig. 1 the limiting value of φ is 81°, and the limiting gradient 0.063; in fig. 2 the limiting values are $54\frac{1}{2}°$ and 0.014; and in fig. 3 the limiting values are 80° and 0.057.

The rate of fall of pressure, or the fall of p per hour, should be taken from a series of readings if possible. Thus from Table 1 we have:

	P.	Diff.
August 11, 1903, 6 a. m.	29.686	
		0.077
August 11, 1903, 7 a. m.	29.609	
		0.089
August 11, 1903, 8 a. m.	29.520	

By taking the mean of the two differences we have 0.083 as the rate of fall at 7 a. m.

We can now show that equation (1) is of some use even at an isolated station. Suppose a cyclone should generate 900 miles away from the station; then, assuming $c = 2$ and neglecting a, the fall of pressure below mean will be 0.067. Suppose next day the cyclone has approached to 530 miles; then the fall below mean will be 0.087. Consequently for two days or so the pressure will be about 0.08 below the mean, no other change having taken place.

I have often called attention to this rather sudden drop in the barometer as a most valuable wireless message from the cyclone to put the observer on his guard. As the cyclone approaches, clouds, wind, and the continued fall of p supply the observer with information; and perhaps the following considerations may aid him.

If the center is advancing along a line drawn through the center and the place of observation, we have,

$$\text{Gradient} = \frac{\text{rate of fall at observatory}}{\text{velocity of center}};$$

or in the notation of the differential calculus,

$$\frac{dp}{dr} = \frac{\frac{dp}{dt}}{\frac{dr}{dt}} \qquad (2)$$

But from (1)

[1] There was great loss of life; 60 or 70 vessels were driven ashore or sunk at their moorings, including the Royal Mail steamship *Rhone* and the West India and Pacific steamship *Columbian*. The latter arrived an hour before the storm with a full cargo from Liverpool and sank in seven fathoms of water. The *Rhone* was the transatlantic steamer which in those days used to meet all the intercolonial steamers at St. Thomas; as she was sinking her boilers exploded and 160 persons on board lost their lives.

$$\frac{dp}{dr}=\frac{c}{2(r-a)^{\frac{3}{2}}}=\frac{\Delta p}{2\,(r-a)}$$

and substituting for $\frac{dp}{dt}$ we get

$$\frac{r-a}{\frac{dr}{dt}}=\frac{\Delta p}{2\frac{dp}{dt}}$$

But, neglecting a, the left hand term in this equation is the time in hours that the central calm will take to reach the station; so that,

$$\text{Time of arrival}=\frac{\Delta p}{2\frac{dp}{dt}} \tag{3}$$

In words, *the time of arrival is the fall below mean divided by twice the rate of fall.*

If, therefore, we find that our series of observations agree in indicating the same time of arrival, there can be no doubt but that the cyclone is directly approaching.

As an example of equation (3), we have already seen that by Table 1, $\frac{dp}{dt}$ was 0.083; and as Δp was 0.32 at that hour, the computed time of arrival is 9 a. m., which is quite correct.

In order to add to this series of cases, let us take the cyclone which passed over Kingston, Jamaica, August 18, 1880. This was before the weather service was established there, so that Kingston was really an isolated station. The cyclone approached from the Windward Islands, and, according to the chart in Meteorological Observations, Vol. I, the cyclone center was not directly approaching till noon, when it turned on its course and made straight for Kingston.

TABLE 5.—*Kingston, August 18, 1880.*

Hour.	p.	Δp.	r.	Δp computed.	$\frac{dp}{dt}$	Time of arrival, as computed
	Inches.	*Inches.*	*Miles.*	*Inches.*	*Inches.*	
7 a. m.	29.782	0.14	256	....	....	....
9 a. m.	29.744	0.18	220	....	0.017	2:00 p. m.
11 a. m.	29.714	0.21	184	....	0.014	6:30 p. m.
1 p. m.	29.687	0.24	148	0.22	0.012	11:00 p. m.
3 p. m.	29.666	0.26	112	0.26	0.022	9:00 p. m.
5 p. m	29.597	0.32	76	0.32	0.060	8:00 p. m.
7 p. m	29.428	0.49	40	0.49	0.181	8:30 p. m.
9 p. m	28.874	1.05	$4\frac{1}{2}$	*1.05	....	....

* Measured along the tangent to the curve.

The velocity of the center was 18 miles an hour, and p_m was taken to be 29.922.

The computed times of arrival before 3 p. m. are irregular; this shows that the center was *not* directly approaching. The times subsequently agreed, which shows that then the center *was* directly approaching. The time of arrival computed by equation (3) was 8:30 p. m. and the calm center actually arrived at 9 p. m.

From noon onward, then, equation (1) should hold good, and we easily find

$$a=+12$$
$$c=2.6$$

whence result the computed values of Δp given in Table 5, and in fig. 4, Plate I, in which the limiting values of φ and the gradient are 57° and 0.015.[2]

We will now consider the case of two stations in the Tropics, on the line of usual approach of hurricanes, and connected by telegraph.

Let Δp be the fall below mean at the station nearer the hurricane at the time t; and let t' be the time at the further station when the fall below mean reaches the same value Δp; then if D be the distance between the two stations in miles, the hourly velocity of the center toward the stations will be

$$\frac{dr}{dt}=\frac{D}{t'-t} \tag{4}$$

when the interval $(t'-t)$ must be expressed in hours and decimals of an hour.

Equation (4) is, of course, independent of (1), and holds good for any relation between Δp and r, provided that Δp increases as r decreases.

Hence, by the mutual exchange of barometer readings by telegraph, each station may come to know $\frac{dr}{dt}$, and hence predict the time of arrival of the center.

Take for example the cyclone of 1886 (Tables 2 and 3). At 7 a. m. on the 19th Δp at Kingston was 0.14; but Δp did not reach 0.14 at Montego Bay until 4 p. m. And as $D=83$ miles, we have $\frac{dr}{dt}=$ velocity of center $=9$ miles an hour.

Similarly for $\Delta p=0.17$, we get $\frac{dr}{dt}=$ velocity of center $=17$ miles an hour. The mean of these two computed values is 13, while the true observed value was taken as 12 miles per hour.

Again, as each station can, from its local observations, also find its own $\frac{dp}{dt}$, or rate of fall at any instant, it follows from (2) that by the exchange of telegrams, each station can calculate its own gradient at the given instant, or $\frac{dp}{dr}=\frac{dp}{dt}\Big/\frac{dr}{dt}$, quite free from any theory.

Consequently each station can compute its

$$r=\frac{\Delta p}{2\frac{dp}{dr}} \tag{5}$$

In words, the distance of the calm area at any time is the fall below the mean divided by twice the gradient.

Thus for the storm of 1903, at Montego Bay, we have found that $\frac{dp}{dt}$ was 0.083 at 7 a. m., but as $\frac{dr}{dt}$ was 20, therefore, $\frac{dp}{dr}$ was 0.00415; and by equation (5)

$$r=40.$$

The true observed value was 45, or thereabouts.

There is no need to proceed any further at present with the mathematical part of this investigation, but I think that much valuable information might be obtained by the discussion of a large number of tropical cyclones on the plan indicated in this article. We want to know more about a and c, and when and why Δp breaks away from the curve and follows the tangent.

As to the practical part of this inquiry, I do not know that observers can do better during the approach of a cyclone, while waiting for time to pass and further exchange of telegrams, than to put their observations into the forms indicated above. Equation (3) has often saved me anxiety, and I have been able to send the second reassuring general telegram, "not coming our way," after the first general warning to the islands had been issued some hours previously.

[2] This small gradient is surprising, as to my own knowledge the wind reached full hurricane force.

ON THE CONDITIONS DETERMINING THE FORMATION OF CLOUD-SPHERES AND PHOTOSPHERES.

By ARTHUR W. CLAYDEN, M. A.

[From the Monthly Notices of the Royal Astronomical Society, December, 1905.]

In the course of an investigation of the conditions under which clouds may be formed in our own atmosphere certain considerations presented themselves which seem equally ap-